AD-A266 245

...MENTATION PAGE

Form Approved
OMB No. 0704-0188

(2)

2. REPORT DATE
9/1/92

3. REPORT TYPE AND DATES COVERED
Final Technical 5/1/90-9/30/92

4. TITLE AND SUBTITLE
Search for Chaos in Free Shear Flows

5. FUNDING NUMBERS
AFOSR-90-0299
2307/AS

6. AUTHOR(S)
Ho, Chih-Ming, Patrick Huerre and Larry G. Redekopp

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept. of Aerospace Engineering
University of Southern California
University Park, RRB 101
Los Angeles, CA 90089-1191

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR
Directorate of Space Sciences
Bldg. 410, Bolling AFB
Washington, D.C. 20332-6448

N A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFOSR-90-0299
2307/AS

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Publication and release,
Distribution unlimited

12b. ...

93-14673

13. ABSTRACT (Maximum 200 words)

Theoretical studies on the temporal and spatial structure in blunt-body wakes have revealed the necessary conditions under which global, self-sustained oscillations appear and have provided firm criteria for specifying the frequency of these oscillations. The theory has also been employed to describe the preferred mode in jets. The two-dimensional structure of these modes provides a firm basis for describing the spatial structure of the vortex pattern observed in wakes. In addition, a theoretical description of the appearance of the spatial chaos in wake-shear layers, and its representation in terms of a one-dimensional map, has been provided. An experimental facility and necessary instrumentation have been assembled and experiments are in progress on spatial chaos in wake-shear layers. Experimental results have revealed a parameter domain where a temporal vacillation occurs between the Karman mode and the shear layer mode. Interesting results with possible application to thrust-vectoring of base flows have also been identified.

14. SUBJECT TERMS
Turbulence, Chaos, Shear Layers

15. NUMBER OF PAGES
6

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Grant No. AFOSR-90-0299

SEARCH FOR CHAOS IN FREE SHEAR FLOWS

Principal Investigators:
Ho, Chih-Ming
Patrick Huerre
Larry G. Redekopp

Department of Aerospace Engineering
University of Southern California
University Park
Los Angeles, California 90089-1191

September 1, 1992

Final Technical Report
Period: May 01, 1990 to September 30, 1992

Air Force Office of Scientific Research
Bolling Air Force Base
Washington, D.C. 20332-6448

FINAL REPORT

"SEARCH FOR CHAOS IN FREE SHEAR FLOWS"

Grant No. AFOSR-90-0299

A. Theoretical Effort (PIs: P. Huerre and L.G. Redekopp)

1. Stability Properties and Nonlinear Dynamics of Wake-Shear Layers

Stability characteristics and nonlinear interactions have been computed for a family of plane wake-shear layer flows. The important parameters of the problem are the velocity ratio of the shear layer component, the velocity deficit of the wake component, and the Reynolds number. The breaking of the symmetry of the velocity profile by either a finite velocity ratio or an asymmetrical wake component causes the inviscid neutral points to correspond to singular neutral modes. That is, the neutral points are necessarily shifted from the location of the inflection points in the velocity profile. Consequently, the stability characteristics are computed for finite Reynolds number using the Orr-Sommerfeld equation. It is found that the bandwidth of unstable wave number for the sinuous mode decreases monotonically from a nondimensional value of two (for the Bickley wake profile) to a value of one (for a shear layer) as the velocity ratio increases for fixed wake deficit. By contrast, the unstable bandwidth for the varicose mode increases for small velocity ratios and then decreases, ultimately vanishing for a finite, critical value of the velocity ratio. The growth rate for the sinuous mode always exceeds that for the varicose. Hence, on a linear basis, the sinuous mode will always dominate, However, the vortex roll-up pattern depends on whether there are one (i.e., shear layer roll-up) or two (i.e., Karman wake roll-up) critical levels in the flow for the sinuous mode, and this is determined by the phase speed of the leading eigenmode based on the asymmetric velocity profile. Conditions for the transition between these vortex patterns have been obtained. Experimental results show that there is a vacillation between these two types of vortex roll-up when the flow conditions are close to this transition. This vacillation is not fully understood and will be the object of future studies. The boundary in velocity ratio--wake deficit parameter space separating domains where the flow is absolutely or convectively unstable has been computed to guide the experimental program and interpret results. Nonlinear interaction coefficients have been computed for the interaction between the sinuous and varicose modes in the convectively unstable domain. It is found that the nonlinear interaction between the sinuous and varicose modes increases dramatically as the symmetry of the wake is broken by a small shear component. This derives from the fact that slight asymmetry in the velocity profile forces the leading order eigenmode to be singular, resulting in strong mean flow distortion in the critical layer. The interaction of these modes, in the convectively unstable regime when forced at a fixed location (like the wake origin), can be reduced to a 1-D map which admits windows of chaotic dynamics depending on the forcing frequency. The chaotic dynamics correspond to intermittent bursts of the varicose mode.

2. Frequency and Pattern Selective in Wakes

A symmetry-breaking bifurcation occurs with consequent unsteady vortex roll-up leading to a staggered array of vortices known as the Karman vortex street when the Reynolds number for flow over a bluff body exceeds a critical value. We have shown that the appearance of this unsteady, asymmetric flow state in a plane perpendicular to the body axis is related to the destabilization of a global mode via a Hopf bifurcation. That is, a finite-amplitude, discrete-frequency, streamwise eigenmode with long-range spatial coherence appears which is manifested in terms of a regular street of vortices. The existence of this global mode is intimately linked to a streamwise window in the spatially-developing wake flow where velocity profiles are absolutely unstable. This embedded pocket of local absolute instability serves as an intrinsic resonator exciting the discrete-frequency motion in the convectively-unstable wake downstream. The interpretation of the dynamics of two-dimensional wakes at Reynolds numbers in the vicinity of and moderately above the critical value in these terms is quite firmly established. Our work has provided explicit selection criteria for the frequency of these modes and information concerning the optimal spatial location for forcing them when they are weakly damped.

A dissipative-dispersive wave model, whose form is justified by asymptotic analysis, has been studied to elucidate the streamwise-spanwise pattern selection for vortex roll-up structure in wakes of finite aspect ratio. The model is a variable-coefficient, two-space-dimensional Ginzburg-Landau equation which consistently describes the finite-amplitude, discrete-frequency global mode. The model provides a firm basis for understanding observed pattern selection mechanisms. For example, when the flow domain possesses spanwise homogeneity with a characteristic shedding frequency ω_b in the bulk and symmetric sidewall boundary conditions are imposed with frequency $\omega_s < \omega_b$, two different flow states are possible depending on the frequency difference $\Delta\omega = \omega_b - \omega_s > 0$ and the aspect ratio. One spatio-temporal pattern consists of a chevron shape which is described in terms of a stationary wave-number shock. A Burgers equation model is derived to describe the phase-front propagation leading to this state. If the sidewall boundary conditions are not symmetric, a stationary wave number shock cannot be formed and an asymmetric shedding pattern is formed with the frequency determined by the sidewall condition with the largest $\Delta\omega$. A second pattern emerges as the frequency difference $\Delta\omega/\omega_b$ is increased at fixed aspect ratio or if the aspect ratio is increased at fixed frequency difference. This state consists of two sidewall layers with oblique shedding and a central, bulk region of (nearly) parallel shedding. These regions are separated by thin dislocation layers or phase shocks. The different patterns can be understood from the necessary conditions for the existence of a global mode and the absolutely unstable domain. Representative portraits of the temporal evolution of these different patterns at a fixed spatial position have been computed and scaling relations for these patterns have been obtained.

The model has also been used to investigate the spatio-temporal pattern selection when the flow domain is inhomogeneous in the spanwise direction. Two types of inhomogeneity, one with a step-function discontinuity simulating the juncture between two bluff bodies of dissimilar scale and one with a constant gradient simulating flow over a body with spanwise taper, have been studied. In the first case, an internal phase shock is forced and its characteristics are studied. In the latter case, free, internal cells with constant frequency shedding are formed and the selection criteria for these cells are identified. The specified spanwise gradient imposes a spanwise strain on the global mode and its discrete-frequency eigen-mode structure and phase shocks form separating adjacent cells of constant frequency shedding. The characteristic width of these cells and their frequency jump are related to the imposed spanwise strain. The results provide a good qualitative insight to the pattern selection principles underlying the observed structure of vortex roll-up in wakes behind two-dimensional or quasi-two-dimensional bodies.

PRIMARY PUBLICATIONS

J.M. Chomaz, P. Huerre & L.G. Redekopp. 1987. "Models of hydrodynamic resonances in separated shear flows". Proc. of the Sixth Sym. on Turb. Shear Flows, Toulouse, France.

J.M. Chomaz, P. Huerre & L.G. Redekopp. 1988. "Bifurcations to local and global modes in spatially-developing flows". Phys. Rev. Lett., Vol. 60, No. 1, pp. 25-28.

J.M. Chomaz, P. Huerre & L.G. Redekopp. 1990. "The effect of nonlinearity and forcing on global modes". New Trends in Nonlinear Dynamics and Pattern-Forming Phenomena: The Geometry of Nonequilibrium", NATO ASI Series B: Physics, Vol. 237, pp. 259-274, Plenum Press, New York.

J.M. Chomaz, P. Huerre & L.G. Redekopp 1991 "A frequency selection criterion in spatially-developing flows" Stud. Appl. Math., Vol. 84, pp. 119-144

D. Wallace & L.G. Redekopp 1992 "Linear instability characteristics of wake-shear layers" Phys. Fluids A, Vol. 4, No. 1, pp. 189-191

D. Park & L.G. Redekopp 1992 "Breakdown of a coherent global mode" Phys. Lett. A, Vol. 164, Nos. 3 & 4, pp. 289-294

D. Park & L.G. Redekopp 1992 "A model for pattern selection in wake flows" Phys. Fluids A, Vol. 8, No. 4, pp. 1697-1706.

SECONDARY PUBLICATIONS

V. Djordjevic & L.G. Redekopp 1988 "Linear stability analysis of nonhomentropic, inviscid compressible flows" Phys. Fluids, Vol. 31, No. 11, pp. 3239-3245.

S. Pavithran & L.G. Redekopp 1989 "The absolute-convective transition in subsonic mixing layers" Phys. Fluids A, Vol. 1, No. 10, pp. 1736-1739.

V. Djordjevic & L.G. Redekopp 1989 "Nonlinear stability of subsonic mixing layers with symmetric temperature variation" Proc. Roy. Soc. London, Vol. A426, pp. 287-330.

V. Djordjevic & L.G. Redekopp 1990 "The effect of profile symmetry on the nonlinear stability of mixing layers" Stud. Appl. Math., Vol. 83, pp. 287-317

B. Experimental Effort (PI: C.-M. Ho)

FREE SHEAR FLOWS CONTROLLED BY TRAILING EDGE SUCTION OR BLOWING

Introduction

The free shear layer is known to be sensitive to upstream boundary conditions. Many experiments have shown that low level perturbations can alter the evolution of the shear flow. In this experiment, we demonstrate that a steady suction or blowing can significantly change the instability process. A threshold suction velocity was found. When the suction is higher than the threshold, the wake becomes stable and no vortex shedding exists and the shear region of the mixing layer can change its direction significantly.

The global development of a free shear layer, mixing layer or wake, depends on the evolution of the coherent structures (Brown and Roshko 1974, Winant and Browand 1974, see review Ho and Huerre 1984). The vortices change their arrangement by mutual induction of neighboring structure. Therefore, the flow can be controlled by applying active forcing to 2-D vortices (Ho and Huang 1982, Oster and Wygnanski 1982). The spreading of actively controlled shear flows can be much higher than that in the unforced case. The perturbation level usually required to make the difference is very low because the forcing is used only as a seeding energy and the shear flow acts as a spatial amplifier of disturbances injected upstream. The instability will, therefore, make the seeding energy grow exponentially with streamwise distance. This occurs because the mixing layer is convectively unstable with all unstable disturbances growing in the downstream direction. The propagation properties of shear flow instabilities are very sensitive to the shape of the velocity profile (Huerre and Monkewitz 1990).

In some flows, like a wake for example, the velocity profile experiences significant streamwise development and the propagation properties of local instabilities can change character along the flow direction. In particular, there may exist a region of significant streamwise extent where local instabilities may propagate in both the upstream and downstream direction (i.e., the flow is absolutely unstable). Furthermore, if the region of local absolute instability is sufficiently large (specific criteria are known), a global resonance can be destabilized which "organizes" the flow over long streamwise scales. The Karman vortex wake behind a cylinder has been shown definitively to be a manifestation of this type of global resonance. What is of particular significance is the possibility of controlling global flow characteristics through modification of local velocity profiles.

At present, we are investigating the effect of modified mean velocity distribution on the stability process and global flow features in a free shear layer configuration. Phenomenal changes are observed with a constant suction or blowing at the origin of the flow. Visualization results were obtained by using the hydrogen bubble technique. Some LDV, PIV and hot-film measurements were made in the flow with suction.

FACILITY

The experiment was performed in an open surface water channel. The stagnation chamber was separated by a vertical splitter plate. Flows in the two sections was provided by two pumps so that the velocity ratio could be easily adjusted. Honeycomb and six layers of screens was used to reduce the mean flow uniformity and the turbulence level. Since the splitter plate was vertical in this case, the problem of removing the air bubbles from the screens was not be difficult. The splitter plate divided the test section into two equal parts, each 21.3 cm wide and 30.48 cm deep. The maximum velocity was be 20 cm.sec.

The trailing edge of the splitter plate was a slot 1 cm wide. A perforated tube inside the slot was connected to a pump. The tube provided either suction or blowing by changing the connection to the pump.

The flow was visualized by the hydrogen bubble technique and the velocity was measured by laser Doppler velocimetry, particle image velocimetry and hot-film probes.

EXPERIMENTAL FINDINGS

1. Wake Modified by Suction

At zero suction velocity, typical wake vortices can be seen by using the hydrogen bubble technique. There exists a threshold suction velocity. Above that value, the vortices disappear. The flow becomes stable for a long distance. The threshold velocity, U_{TS}, is linearly proportional to the free stream speed of the wake, U. The hot-film provides vortex induced velocity fluctuations when no suction is applied. The time trace shows an amplitude modulated sinusoidal. The vortex shedding frequency decreases with increasing suction velocity. The Strouhal number, St, normalized with the width of the slot, D, and the velocity difference, $U - U_c$, has a constant value of 0.12. U_c is the suction speed. As the suction velocity gets closer to the threshold, the vortices become intermittent. As soon as the threshold velocity is reached, the fluctuation vanishes and the hot-film output is almost constant as a function of time.

2. Wake Modified by Blowing

When the blowing speed is about 10% of the free stream speed, the width of the wake is reduced to half of the one without blowing. The vortex pattern is the same as that of a typical wake although the vortices are smaller.

3. Mixing Layer Modified by Suction

Two velocity ratios were tested in the mixing layer mode. At R = 0.3 and 0.6, vortices were observed in the cases without suction. While the suction velocity is increased to become higher than the threshold velocity, the mixing layer will turn toward the low speed side at about 35°.

4. Mixing Layer Modified by Blowing

No significant difference was observed between low and high velocity ratio mixing layers. The blowing also reduced its spreading. Due to the presence of the boundary layers along the two walls of the slot, two wake-mixing-layers form in the shear region. It is interesting to note that a string of vortices first starts on the wake-mixing-layer of the low speed side. Further downstream, another stream of vortices forms on the high speed side wake-mixing-layer.

REFERENCES

G. Brown & A. Roshko. "On density effects and large structure in turbulent mixing layers". J. Fluid Mech., 1974, 64, part 4: 775-816.

Ho, C.M. & L. Huang. "Subharmonics and vortex merging in mixing layers". J. Fluid Mech., 1982, 119: 443-473.

Ho, C.M. & P. Huerre. "Perturbed free shear layer". Annual Reviews of Fluid Mech., 1984, 16: 365-424.

P. Huerre & P. Monkewitz. "Local and global instabilities in spatially developing flows". Annual Reviews of Fluid Mech., 1990, 22: 473-537.

D. Oster & I. Wygnanski. "The forced mixing layer between parallel streams". J. Fluid Mech., 1982, 123: 91-130.

C. Winant & F.K. Browand. "Vortex pairing: The mechanism of turbulent mixing layer growth at moderate Reynolds number". J. Fluid Mech., 1974, 63: 237-255.

PUBLICATION

Ho, C.M. & T.S. Leu. "Stable and unstable wakes behind a blunt trailing edge". IUTAM Symposium on wakes behind a Bluff Body, Germany, September 7-11, 1992.